The effect of recycling on provenance determinations

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Sedimentary rocks and modern sediments sample large volumes of the Earth's crust, and preserve units that vary greatly in age and composition. Determining the provenance of component minerals is complicated by the ability of some minerals to be recycled through multiple sedimentary cycles, so minerals from completely unrelated sources may end up in the same sedimentary basin. To untangle these multi-stage signals, two or more chemical signatures measured in minerals with different stability are required. For instance, labile minerals, such as feldspar, can break down rapidly during sedimentary transport, while refractory minerals, such as zircon, can be much more resilient and survive repeated recycling.

One sedimentary succession suitable for testing this hypothesis is the Upper Carboniferous Millstone Grit Group, a fluvio-deltaic, upward-coarsening sequence of mudstones, sandstones and conglomerates deposited in the Pennine Basin of northern England over *c*. 14 myr. New isotopic data have been measured in detrital K-feldspar and zircon from five of the seven stages, complementing previous work in the area [1,2,3]. Two K-feldspar Pb isotope peaks at $^{206}Pb/^{204}Pb$ = 12.5–15.5 and *c*. 18.4 indicate derivation from Archaean–Proterozoic basement and Caledonian granites, respectively. Zircon U–Pb age peaks at *c*. 2700, 1000–2000 and 430 Ma reflect a mixture of Archaean basement, Proterozoic sediments and Caledonian granites, while Hf model ages form two broad peaks at *c*. 4500–3000 and 2300–1500 Ma, indicating contributions from both juvenile and reworked crust.

Strong similarities between potential sources in this complicated region mean no one mineral or isotopic system can provide a unique provenance determination. Instead, comparing first-cycle and multi-cycle minerals with different hydrodynamic properties is necessary to untangle the full story. Combining these results with published garnet, monazite and muscovite data demonstrates the power of multi-proxy provenance work, indicating a primary source area in the Greenland Caledonides, with minor contributions from Norway and Scotland. Comparisons between zircon U–Pb distributions in Palaeozoic sediments suggest long-lived sedimentary systems recycled material around the North Atlantic over *c*. 100 myr, much of it ultimately derived along the Grenvillian margin of Laurentia. This consistency is interrupted only by regular variations in palaeoflow direction, reflecting tectonic evolution in the region.

[1] Tyrrell *et al.* (2006) *J. Sed. Res.* **76,** 324-345.
[2] Hallsworth *et al.* (2000) *Sed. Geol.* **137,** 147-185.
[3] Hallsworth & Chisholm (2008) *Sed. Geol.* **203,** 196-212.